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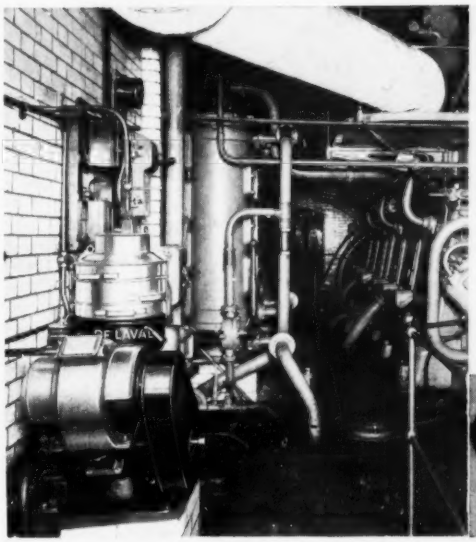


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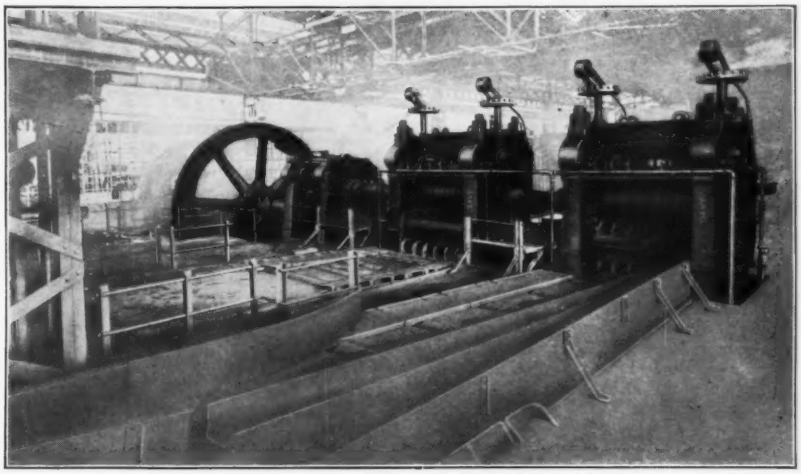

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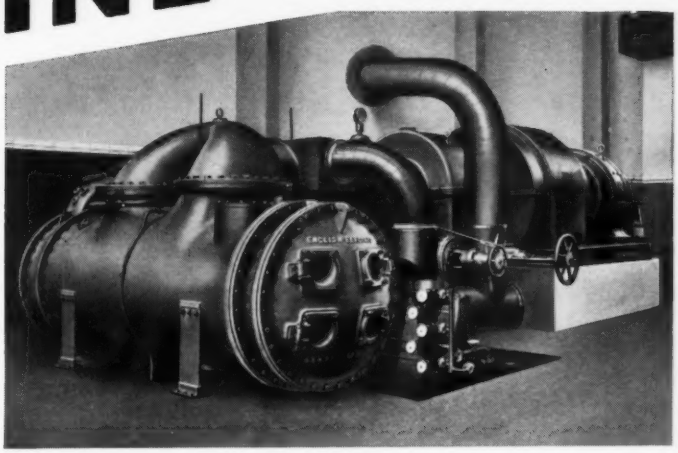

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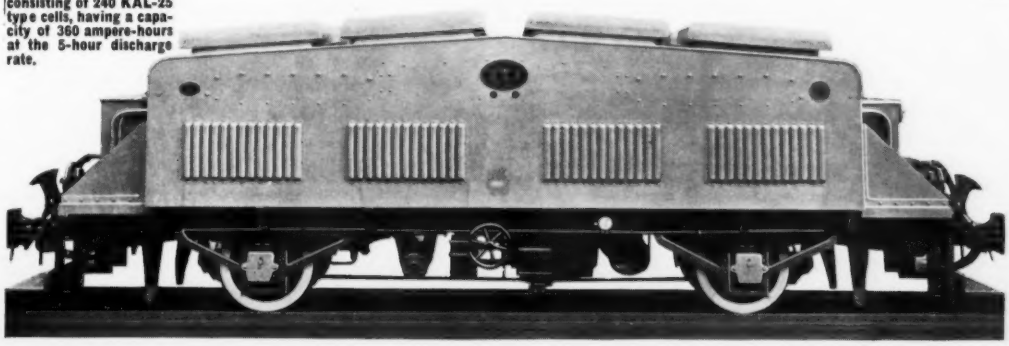

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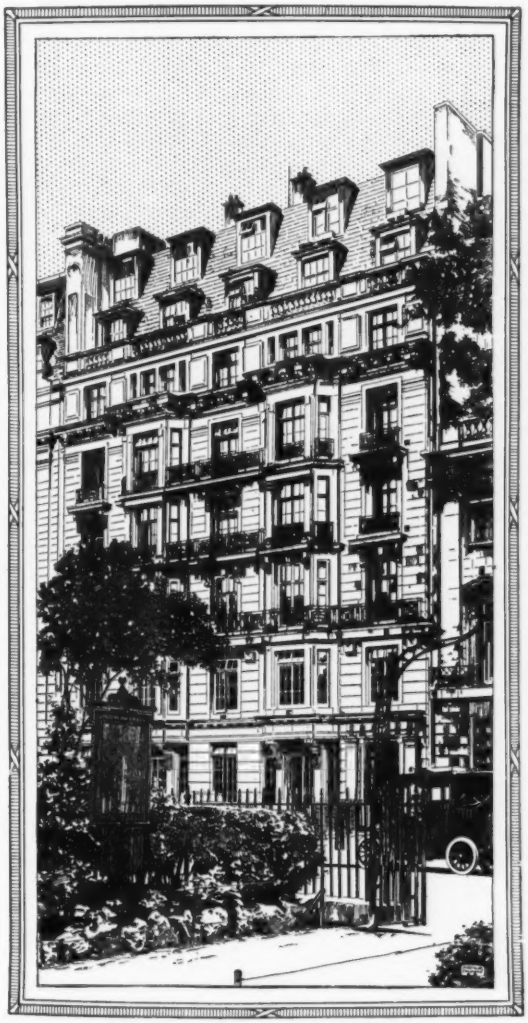

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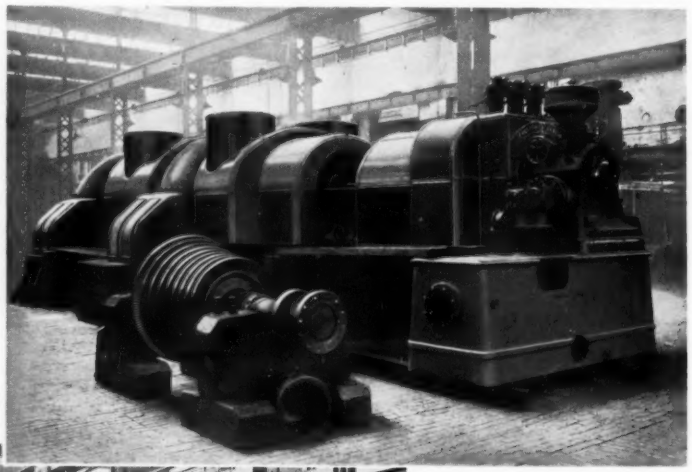

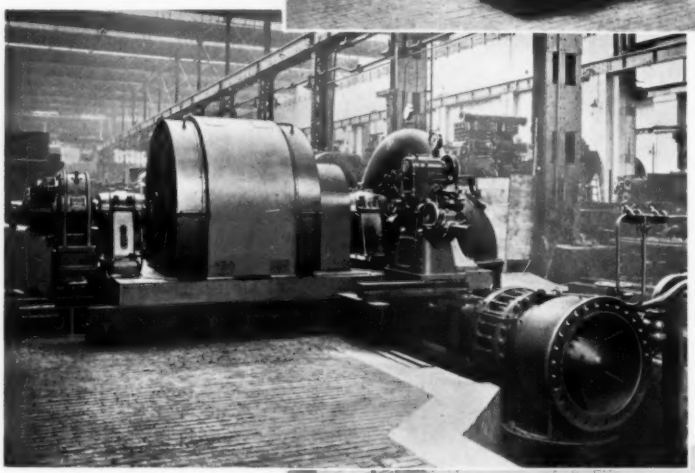

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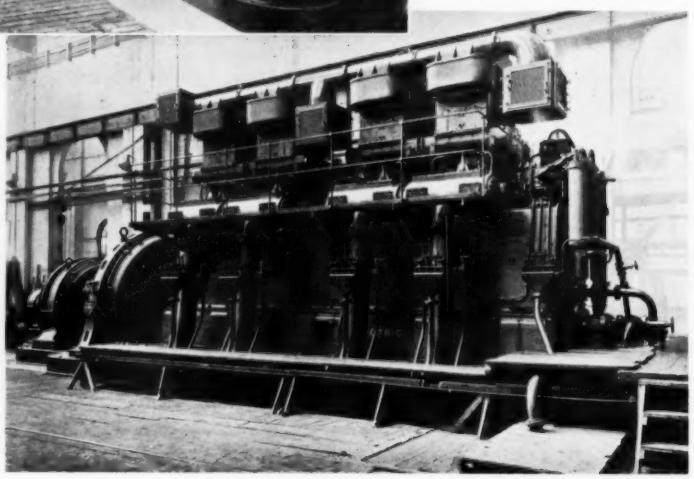

# The English Electric Journal

Vol. V. No. 6 JUNE, 1931 One Shilling.

## CONTENTS.


| | PAGE |
|---|---|
| London's First Trolley Buses | 136 |
| Motherwell Iron and Steel Company's New Sheet Mill Opened | 138 |
| New Main Switchgear at Hastings | 138 |
| Frequency Standardisation in Great Britain | 139 |


*All Communications respecting Editorial Contents should be addressed to* The Editor, The English Electric Journal, Queen's House, Kingsway, London, W.C.2.

## EDITORIAL.

The more spectacular work of the Central Electricity Board, that is to say the system of overhead power lines forming the Grid, is well known even to the man in the street; but there is another vast undertaking of that wonderful organisation which is not brought so prominently before the public notice.

The work we refer to is the conversion of existing 25 and 40 cycle areas of supply to the standard periodicity of 50, and embraces the great industrial districts of Central Scotland, Central England and North East England. Not only are changes in generating station and substation plant involved, but also corresponding changes in every individual motor and consuming device throughout these areas. The total cost is estimated at eighteen million pounds, and the amount of detailed engineering work that the change entails is enormous. There is the further complication that the change-over in each area must be tackled piece-meal, and that provision must be made for the continued use of consumers' machinery, etc., throughout the change-over period.

The work will extend over a number of years, and there is but little doubt that, as in the case of the railways, when the broad gauge was converted to standard gauge, the ultimate gain will more than compensate for the cost and labour involved, and that the bold policy of the Electricity Commissioners and of the Board will be amply justified.

As regards the methods of conversion there is no one solution that applies in all instances. Each case must be considered on its merits, and to obtain the best results

engineering skill of a high order is required. Plant and apparatus that can operate on dual frequencies is in many instances necessary, in order to bridge over an extended period of transference, and in practically every case questions of speeds, mechanical arrangements, efficiency and power factor must be carefully investigated.

There is another aspect of the change-over that is of great importance. Seeing that of necessity much new plant has to be installed, opportunity presents itself for consumers to modernise their power equipments and bring them right up to date. Improvements that otherwise would be impossible, owing to financial or other reasons, at once become practicable, if only thought is taken prior to the conversion; and it is to be noted that only the extra cost, if any, of such improvements falls upon the consumer, the cost of the conversion itself being borne by the Board.

In the following pages some typical conversions are described, and the reader will obtain a good idea of the alternative possibilities that present themselves for consideration. The English Electric Company has specialized in this class of work, and has on its staff engineers who have acquired much experience of change-over problems. The Company will be glad to place the services of these experts at the disposal of engineers and others who have such problems to consider.

## London's First Trolley Buses.

About 17 miles of the system of the London United Tramways in Surrey are in course of conversion to trolley-bus working. The first service was inaugurated on May 16th, when eight of the thirty-five vehicles that have been equipped by the Company were brought into use on the Twickenham Junction - Teddington route. The undertaking had been faced with the necessity of heavy expenditure on their tram track and vehicles, and decided that the adoption of trolley buses would be advantageous in point of economy and traffic efficiency.

*Transport progress illustrated at the opening of the L.U.T. Trolley Bus Service.*

The first trolley bus was set in motion by the Mayor of Twickenham, who rode to Teddington and back accompanied by a number of officials representing local authorities, and at the conclusion of the inaugural run the company returned to the Fulwell Depot for lunch and a close inspection of the new vehicles. The Underground group of Companies was represented by the Managing Director, Mr. Frank Pick, and the London United Tramways by the General Manager, Mr. C. J. Spencer. General satisfaction was expressed at the smooth and quiet running and the rapid acceleration and powerful braking of the buses. When fully loaded they are capable of a speed of 29½ miles per hour on the level and 18 miles per hour on a 5 per cent. gradient. Acceleration is up to 3 ft. per second per second, which permits 20 miles per hour to be attained in 10 seconds within a distance of 62 yards. Retardation can be effected at 8 ft. per second per second for ordinary stops, and at 12 ft. per second per second for emergency stops, these rates being uniformly continued until the vehicle comes to rest. In emergency a bus that is running at 30 miles per hour can be brought to standstill in about 80 ft.

*Another view of one of the L.U.T. Electric Buses.*

The vehicles are double-deck 56-seaters of the "A.E.C.-English Electric" type, fitted with an 80 H.P. 500-volt motor and contactor type control gear of the Company's well-known designs; speed control is effected by a pedal that actuates a 6-notch master controller. Three braking systems are provided, hand, rheostatic and vacuum, the two latter being operated in succession from one pedal.

Another recent delivery of "A.E.C.-English Electric" vehicles is illustrated on the next page. In the case of these trolley buses for Walsall Corporation the Company constructed the bodies as well as the electrical equipment, and fitted them to A.E.C. chassis. A special feature of the construction is that the body pillars are carried right through to the roof

*"English Electric" Trolley Bus in service at Christchurch, N.Z.*

so that the whole body is constructed as a unit and not as two separate saloons.

The lower illustration on page 137 is of particular interest as it records the putting into operation of the first trolley bus service in New Zealand. This vehicle is one of six similar buses supplied to the Municipality of Christchurch. The chassis and equipments were constructed at Preston Works, but in order to save freight charges the bodies were constructed locally in accordance with the working drawings provided. The design selected is of the one-man type and passengers enter by the side of the driver, who collects the fares; an exit at the rear end ensures quick clearing at the terminus, and, in addition, an emergency door is provided on the "off" side.

*One of the Trolley Buses recently delivered to Walsall.*

**Motherwell Iron & Steel Company opens a New Sheet Mill.** An interesting ceremony took place on May 26th, when the Marquis of Douglas and Clydesdale, M.P., formally inaugurated an up-to-date electrically driven sheet mill equipment, the installation of which marks the first step in an extensive programme for the modernisation of the rolling plant. Mr. A. Victor Wilson, B.Sc., A.M.I.C.E., Chairman of the Company presided, and in the course of his remarks stated that the new mill was capable of rolling sheets up to 16 feet long and 55 inches wide, and from $\frac{3}{16}$ in. thick to 16 and 18 gauge.

This mill is driven by an "English Electric" 2,200-volt slipring induction motor having a peak output of 1,800 H.P. at 270 r.p.m. The pinion shaft carries a $7\frac{1}{2}$ ton flywheel on each side of the pinion and is connected to the motor by a flexible coupling. The equipment includes a step-down transformer, ironclad control switchgear and a liquid-type motor starter.

When the further equipments have been delivered, the Motherwell Iron & Steel Company will have one of the most up-to-date plants in the country. It will operate under ideal conditions since it will be possible to vary the speeds of all the bar mills whilst at the same time a high power factor will be maintained. The improvements are being carried out under the personal direction of Mr. Thomas Harvey, the Managing Director, whose advanced ideas in mill equipment and operation have been embodied in the layout. With him has been associated in connection with the electrical equipment, Mr. Robert A. Jackson of Glasgow.

**New Main Switchgear at Broomgrove Power Station, Hastings.** The inauguration of a 14-panel, 11,000-volt, metal-clad switchboard took place on June 4th, the ceremony being performed by the Mayor of Hastings, Councillor G. H. Ormerod, J.P., supported by the Chairman of the Electricity Committee, Councillor E. M. Ford, and a large gathering of representatives of supply undertakings.

The new board, which is a fine example of the Company's compound-filled switch-gear, acts as a connecting link between the 132kV. sub-station of the Central Electricity Board, which adjoins the power house and the 11,000-volt transmission system that feeds an area comprising some 152 square miles outside the Borough. It was constructed to the specification of Mr. A. J. Ryan, M.I.E.E., A.M.I.Mech.E., the borough electrical engineer, in conjunction with the engineers of the Central Electricity Board.

# Frequency Standardization in Great Britain.

"The installation of the new or altered electrical plant in consumers' premises will contribute to the work of modernizing and re-equipment of many of the most important industrial establishments in the country."—*Third Annual Report of the Central Electricity Board.*

The main feature of the National Electricity Scheme now being put into effect in Great Britain is the connection to a giant busbar system, the so-called "Grid," of all power stations selected for future operation. The chief purpose of the 132,000-volt primary transmission lines which form the "Grid" is to pool the resources of the power stations over considerable areas thereby using the plant to the best advantage, and, as a corollary, reducing the cost and increasing the reliability of electricity supply. This principle having been adopted, the desirability of having a standard frequency became evident.

Nevertheless the difficulties in the way of standardization were very great, for in spite of the predominating frequency being 50 cycles, a few of the largest supply undertakings work at other frequencies. The considerable size of those undertakings and the importance of their power stations in the general scheme rendered the adoption of frequency changers on a large scale impracticable as a final solution, and the Electricity Commission took the bold step of directing a complete change of frequency on all non-standard systems. The cost of the work, which is estimated at more than eighteen million pounds, will be defrayed by the Central Electricity Board in the first instance, and will subsequently be recovered by a levy on the whole of the electric supply undertakings of the country; naturally the changeover process will take several years to complete.

Over and above the main advantage of simplifying inter-connection, a standard frequency will tend to reduce the cost of electrical plant, and, further, as pointed out by the Central Electricity Board, in the paragraph quoted at the head of this article, the changeover will give a wonderful opportunity for improving existing industrial installations at little, if any, additional cost beyond that entailed by the frequency changeover itself.

There will be general satisfaction in the former 25-cycle areas at the elimination once and for

*Fig. 1. The first 50-cycle turbo-alternator set on the Glasgow Corporation system. Output—25,000 kW. at 1,500 r.p.m.*

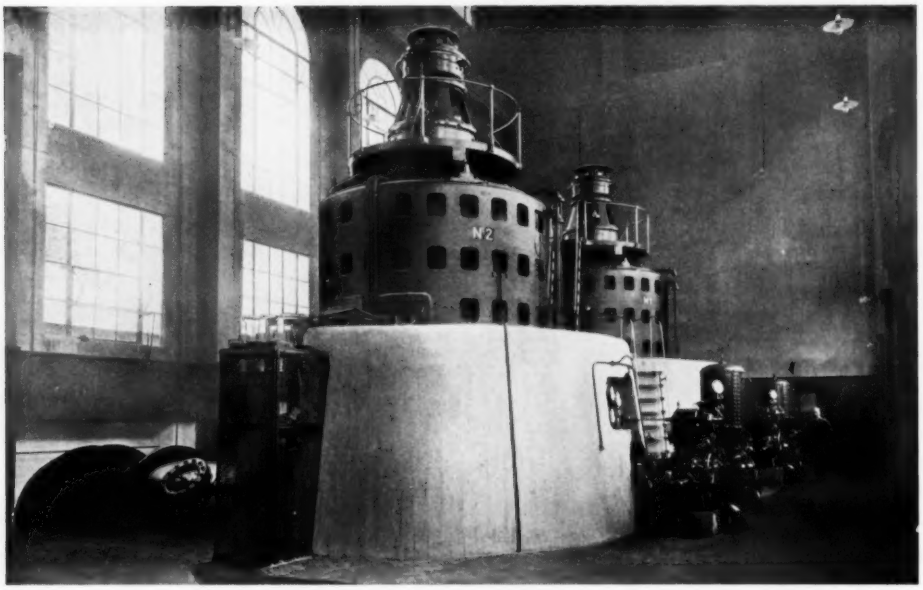


*Fig. 2. 3,550 kVA. Water Turbine Alternators in the Stonebyres Power Station of the Lanarkshire Hydro-Electric Power Co. Built for 25 cycles and converted to 50 cycles.*

all of the flicker, which in spite of many palliatives is unavoidably associated with lighting at so low a frequency.

There are three main areas affected by the decision, and after close investigation with the Supply Authorities concerned, all the financial and technical principles have been defined, and the work commenced. The Central Scotland Scheme provides for changing over the 25 cycle systems of the Glasgow Corporation and the Clyde Valley Electrical Power Co.; the Central England Scheme for a similar changeover on the systems of the Birmingham Corporation and the Shropshire, Worcestershire and Staffordshire Electric Power Co.

Nearly the whole of the former system and most of the industrial area of the latter are supplied at the lower frequency, but the Shropshire, Worcestershire and Staffordshire Company has for some years carried out all its extensions and developed the supply to its wide rural areas at 50 cycles; therefore the changeover affects only the older portion of this system, that is to say, the concentrated industrial load in Smethwick and the southern part of the "Black Country."

Technically and financially the most difficult changeover is that of the highly developed electricity systems in the North-East England Scheme, where the greater part of an area of over five thousand square miles is served at a frequency of 40·8 cycles per second. Some changeover work falls to be done also under the North-West England and North Wales, the South-West England and South Wales, and the South-East England Schemes, but together these account for only about 8 per cent. of the total expenditure on frequency standardization.

The work of superintending the changeover, not only on the supply side, but also in consumers' installations, is delegated by the Central Electricity Board very largely to the undertakings concerned in each area, and the Board states in its latest report that "this procedure has worked harmoniously and satisfactorily, and the undertakers are whole-heartedly carrying out the work, which must of necessity involve them in a great deal of trouble, inconvenience and responsibility."

## THE WORK INVOLVED.

A change of frequency affects every piece of rotating electrical machinery from the power house to the smallest domestic motor, and in varying degrees all electromagnetic apparatus, and the replacement or reconstruction of all this material can be carried out only by easy stages and according to carefully organised plans. The initial step is the provision of a nucleus supply at the standard frequency; subsequent development of the changeover will be assisted by the connecting up of the changeover areas to the "Grid" as they will then be able to draw power at standard frequency from other areas while the remainder of their own plant is reconstructed.

Although the conversion of the power house and substation plant is a large operation, it is entirely in the hands of the Supply Authority to plan the method and the time schedule. The conversion of motors and apparatus on consumers' premises is, on the other hand, an intricate business to which is added the complication of dealing on sound lines with new installations connected to the old frequency during the transition period. Speaking broadly, the plan adopted is to divide the whole area into districts corresponding to suitable sections of the feeder and distribution system. Consumers in each area are notified well in advance of the date on which the supply to them will be at the new frequency; in the interval full advice is given and the necessary financial negotiations are completed.

In some areas the consumer arranges the details of his changeover and the Supply Authority submits his proposals and estimates to the Central Electricity Board for approval, but in the Newcastle Area the authorised undertakers have established a special Change-of-Frequency Department which relieves the consumer of all the detail work connected with the selection and ordering of the new plant. Whatever differences there may be in procedure between one area and another, consumers have the satisfaction of knowing that the Supply Authority is only too anxious to give them a full measure of assistance and advice, so that they will obtain the maximum benefit with the least expenditure.

Whilst the reinstatement of an existing installation by another of equal performance without cost to the consumer is the limit of the legal obligation imposed upon the Board, reasonable elasticity within the expenditure corresponding to that limit is permitted, and in practice many consumers can derive great benefits from the changeover by taking advantage of the opportunity to rearrange their drives and modify the type, distribution and rating of their motors; the excess outlay, if any, that is to be borne by the consumer will generally be quite small in comparison with the economic gain in the operation of his factory.

The method of transferring consumers or groups of consumers systematically from the old to the new frequency, necessarily varies in detail according to the load involved, the time taken to exchange the motors and other apparatus, and the arrangement of the network. In some cases a loop main is fed from one end at the old frequency and from the other end at the new frequency, and the loop is interrupted at the point where changeover work is proceeding; when the desired group of installations is ready for the changeover a further section of the main is transferred from the "old" to the "new" side of the loop.

In large installations it is impossible to change all the motors and carry out the necessary mechanical alterations during a single interruption to normal working, and it may be necessary to run a duplicate service into the Works, or to install a frequency changer temporarily. A temporary switchboard also may have to be installed so that groups of circuits may be changed over from one service to the other merely by switching, without any interruption of important drives, such as colliery fans or pumps.

Of the three principal changeover schemes mentioned earlier two have special characteristics. In the Birmingham area of the Central England Scheme the change of frequency from 25 to 50 cycles is being accompanied by a change, at the cost of the Corporation Electricity Department, in the pressure of the E.H.T. system from 5,000 volts to 11,000 volts, and as a result high-tension

cables, transformers, E.H.T. motors and apparatus will be affected to a greater extent than where the frequency change only takes place.

On the north-east coast where the changeover is from 40 to 50 cycles, the conversion affects the mechanical portions of drives to a more serious extent than where the change of frequency is from 25 to 50 cycles. In the latter case 50-cycle motors are available, as a general rule, which will run at the same speed as the 25-cycle machines previously used, but the speeds which are common to both 40 and 50 cycles are very few, and even those are outside the range of the small and medium horse powers which form the bulk of industrial drives. Consequently in this area the changeover will frequently entail alterations to the mechanical parts and even to the replacement of the driven machines in some cases.

## POWER STATION AND SUBSTATION PLANT

The initial step in the frequency standardization scheme as a whole was taken by Glasgow Corporation, when in accordance with the Board's programme for the installation of a nucleus of 50-cycle generating plant in each area, they installed in May, 1929, a 25,000 kW., 50 cycle turbo-alternator set in their Dalmarnock station. This set is illustrated in Fig. 1.

The turbine is one of the Company's two-cylinder impulse-reaction machines running at 1,500 r.p.m., and operating with steam at 270 lbs. per sq. in. and 700° F. It has carried the 50-cycle load continuously since its installation, giving in emergency an output of 27,500 kW., with a steam economy considerably higher than the guaranteed figure. Subsequently the rewinding of the alternator of a second "English Electric" set in the same station was undertaken, the original turbine being retained in this case.

The other generating authority in the Central Scotland area, the Clyde Valley Electrical Power Company, proceeded on the same lines, and at an early date commenced the conversion of the plant in the two hydro-electric stations of the Falls of Clyde. As a first step the conversion of one of the alternators at Bonnington was undertaken. This machine was rated at 6,150 kVA., 11,000 volts, 25 cycles, and had eight poles. The rating of the reconstructed machine which has sixteen poles and runs at the same speed is 6,220 kV.A. at 11,500 volts and 50 cycles.

The reconstruction involved the supply of an entirely new stator winding, but it was possible to use the existing stator core without modification. The winding is of the basket type connected in two parallel circuits, and the coils are entirely mica insulated. It is of interest to record that when the old coils were removed the insulation was in absolutely sound condition and free from any trace of ionization, or of swelling at the points where the coils cross the radial air ducts in the core.

The new stator coils having been prepared in advance of the dismantling of the machine, work was commenced on the 1st June, 1930, and by

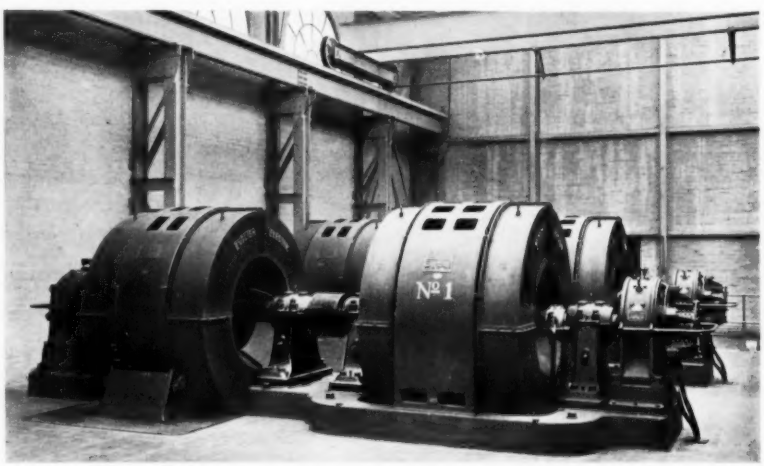


*Fig. 3. Two 2,500 kW 25/50 cycle Frequency Changers in an Industrial Substation in the Birmingham area.*

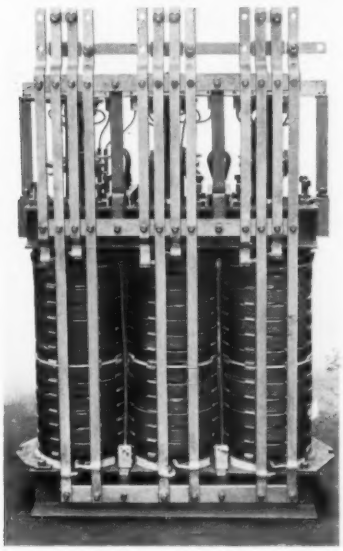

*Fig. 4— Dual-Frequency (25/50 cycle) Double-voltage (5,000/11,000) Three-phase Transformer with tapping switches.*

the 17th July the new winding was complete. The only other modification made to the stator was the replacement of the cast-iron stator coil support rings by "Nomag" rings in order to eliminate the higher stray losses which would otherwise have occurred in this part at the higher frequency.

The rotor was returned to Stafford Works, and the existing poles and coils removed. These poles were solidly fitted into dovetail slots milled in the eight flats of the cast-steel hub. Eight additional flats and dovetail slots were cut between those already existing. The sixteen new poles, consisting of sheet-steel laminations bolted between gun-metal end-plates, had been prepared in advance; they also are provided with dovetails, but owing to the much smaller centrifugal force of each pole, it was possible to use taper side-keys for securing them in the slots. The new field winding, like the old, is of bare copper strip, insulated with mica both between turns and from the metal spool on which it is mounted; it is designed so that the existing exciter is suitable without modification. New coil supports were fitted between each pole, and the original fans remounted on the rotor.

The reconstruction of the rotor was taking place whilst the stator was being re-wound on site. It was reassembled in the stator without delay, and the reconstructed machine was finally brought up to speed on the 18th August, only ten weeks after it has been shut down.

Shortly afterwards, similar reconstruction of the second machine at Bonnington and of the two sets at Stonebyres was commenced on similar lines.

As indicated earlier, the complexity of the changeover operations increases outside the power station. The substations of the supply undertaking and on consumers' premises have to be considered individually and the majority of the transformers and converting units require replacement. Although transformers are very flexible and the change from 40 cycles to 50 cycles, or even from 25 to 50 cycles does not necessarily render them incapable of adaptation, considerations of impedance, new transmission voltage and double frequency operation have rendered replacement essential in many instances.

A 25-cycle transformer operated at the same output on a 50-cycle supply will have a somewhat higher efficiency and run with a lower temperature rise, but due to the doubled reactance its regulation will be poorer, particularly at low power factors. It has been found in practice that on lighting and unity power factor circuits and in situations where good voltage regulation is not of first importance or can be obtained by other means, the old 25-cycle transformers give sufficiently good results on 50 cycles. In other cases and especially for rotary convertor service it is necessary to order new transformers which it is usually worth while to construct as dual-frequency units, combined in the case of the Birmingham changeover with provision for dual-voltage operation. Many units of these types are under construction, and in general the output at the higher frequency is double that given at 25 cycles. Figure 4 shows one of these dual frequency transformers delivered to one of the 25-cycle areas. It is so arranged that by simple reconnection it will operate on a 50-cycle supply and then have double the rating which it had on the original 25-cycle system. It will be seen that

the unit is fitted with tap changing gear on the high-voltage side.

An interesting example of a large dual-frequency unit is one designed to give 7,500 kVA. at 25 cycles and 12,000 kVA. at 50 cycles, the voltage ratio being 33,000/5,500 in both cases. When operating at 25 cycles the connections will be star/inter-star and for 50 cycle operation they will be star/star with a delta-connected tertiary winding; the whole of the windings are used under both conditions. The 33 kV. side is a simple series-parallel arrangement. On the L.V. side the inter-star connection is made up of a portion that will eventually be used for the tertiary, the remainder being used for the star-connected L.V., and the two portions of each required to form the inter-star connection are connected in parallel for 50-cycle working. On-load tap-changing is provided on the H.V. side giving plus and minus 15 per cent. in 2.15 per cent. steps on both frequencies.

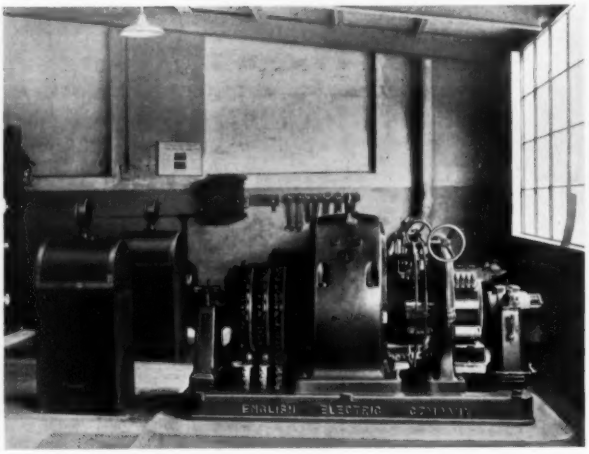

*Fig. 5. 150/300 kW., 25/50-cycle and 300 kw., 50-cycle Rotary Convertor Equipments in a Motor Tyre Works.*

The modification or replacement of converting plant has, up to the present, been carried out to a greater extent in the substations of industrial works, than in those of the public supply undertakings, for the reason that the former is obviously the more urgent case. Many large works have their own converting plant to provide direct current for special variable-speed drives and other purposes, and a great many orders have been executed both for replacement or reconstructed machines and for dual-frequency convertors; the former are often arranged to suit existing bed-plates. The Company's design of 25/50-cycle convertor equipments is such that the necessary adaptation to the new frequency can be made on site and the output is then double the 25-cycle output with substantially the same performance characteristics. In some cases the equipment can be used for 50-cycle working without alteration, but the flux loading is then halved and the characteristics altered. For 40/50-cycle service no change is made to the convertor or transformer on the occurrence of the changeover.

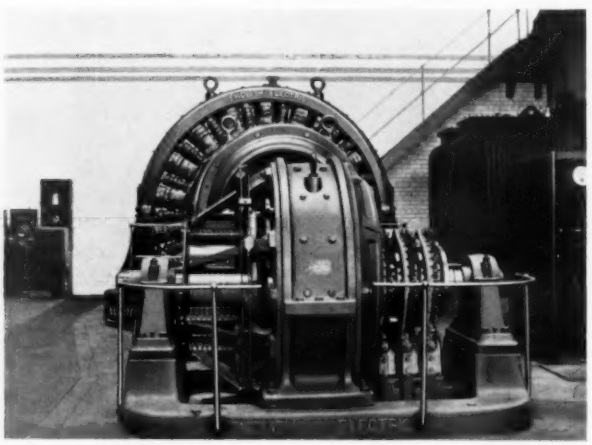

*Fig. 6. 600 kW., 25/50-cycle and 1,200 kW., 25-cycle Rotary Convertors in a steel works.*

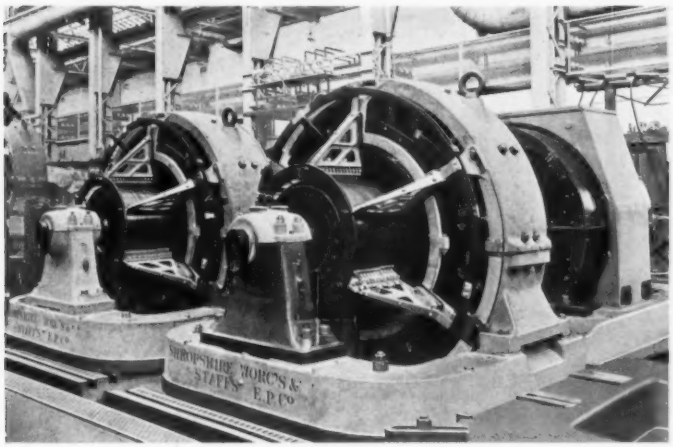


*Fig. 7. 1,250 kW. 11,000-volt., 50-cycle Motor Convertors to replace 25-cycle Rotary Convertors.*

Fig. 6 shows a 300/600-kW. 25/50-cycle convertor in a steelworks, which represents the first step in the replacement of the single 1,200-kW. 25-cycle convertor seen behind it. A 600-kW. straight 50-cycle equipment is now in hand, and when this is installed the old unit will be removed. Another instance of an industrial substation is that shown in Fig. 5. When extension of the works was planned before the changeover, a 150/300-kW. 25/50-cycle dual-frequency convertor equipment was installed, and after the changeover a similar straight 50-cycle unit was added.

Fig. 8 shows a docks substation with two 200-kW. 40/50-cycle convertors, with the site for a third unit of 400 kW., which has since been installed.

As an example of main substation plant supplied in connection with the changeover, two 1,250-kW. 11,000-volt 50-cycle motor-convertors are shown in Fig. 7. These have been constructed to replace two 25-cycle rotary convertors and transformers on the system of the Shropshire, Worcestershire and Staffordshire Company. They embody a number of special mechanical and electrical features that have been standardised in "English Electric" plant of this kind.

It can readily be understood that although the idea of using frequency changers as a main link between systems of non-standard frequency and the "Grid" could not be contemplated, these machines are an economical solution of some of the problems encountered in dealing with large private installations, especially new equipments in districts where a supply at the standard frequency will not be available for some time. Such installations can be carried out with 50-cycle motors and apparatus and operated from a fre-

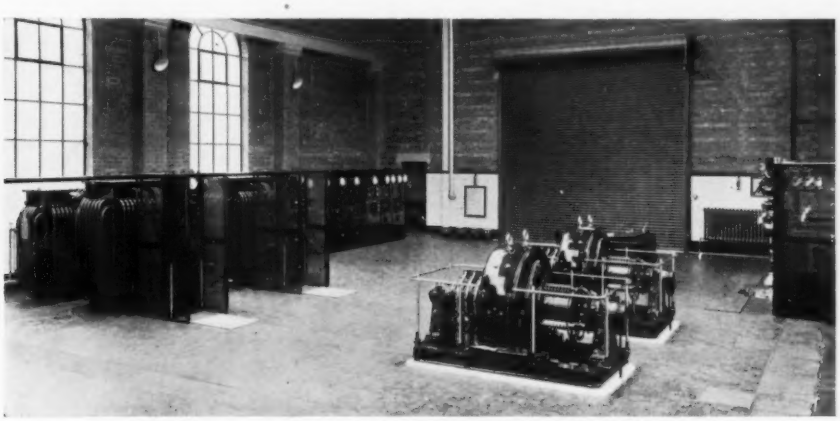

*Fig. 8. Substation on N.E. coast, containing 40/50-cycle Rotary Convertor Equipments.*

quency-changer installed by the supply authority in the works substation. The converse case of using temporary frequency-changers—constructed sometimes on self-contained transportable frames—has already been mentioned ; they permit the change-over of a large works to be spread over a reasonable time by affording a supply at both frequencies. An example of a machine of this type is shown in Fig. 12.

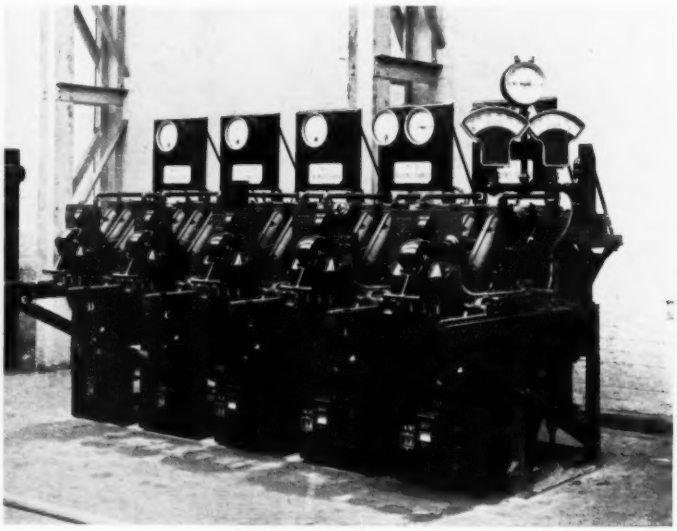

*Fig. 11. 11,000-volt Metalclad Compound-filled Mill Switchboard.*

Figs. 3 and 10 show two 2,500-kW. frequency-changers and their switchboards in a metal-working factory in the Birmingham area, and Fig. 9 the metal-clad switchboard controlling the 50-cycle supply to the factory. These units take their supply at 5,000 volts, 25 cycles and generate at 11,000 volts on the 50-cycle side, but are designed to be reversible. They are equipped with motor-operated stator adjusting gear and automatic voltage regulators, and are designed for starting up from the 25-cycle side initially, but later the same gear will be used for starting from the 50-cycle supply ; starting is accomplished by means of a dual-frequency auto-transformer. The sets have four bearings, so that at a later date the individual machines may be utilised as synchronous condensers.

The use of frequency-changers on a larger scale is exemplified by the installation of some large units on the system of the Newcastle-upon-Tyne Electric Supply Company. Fig. 11 shows a 7,500-kW. unit in course of construction ; it will be installed at the North Tees Power Station in order to give a supplementary 50-cycle supply to Darlington Corporation, at whose station additional plant is not due for installation under the Board's scheme until 1937/38. The set is designed so that at a later date each machine may be used as a synchronous condenser on 50 cycles, and the bedplate is constructed to facilitate the separation of the units. Motor-operated stator rocking gear is being provided, and the starting equipment will be of the auto-transformer type with "start" and "run"

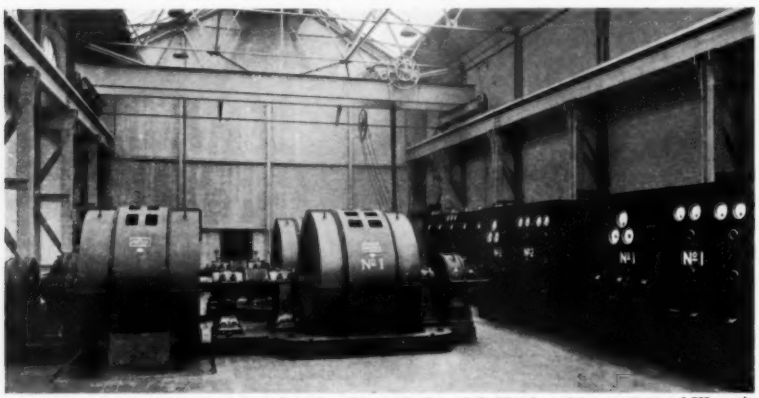

*Fig. 10. Frequency-Changer substation in an Industrial Works with two 2,500-kW units for 5,000/11,000 volts.*

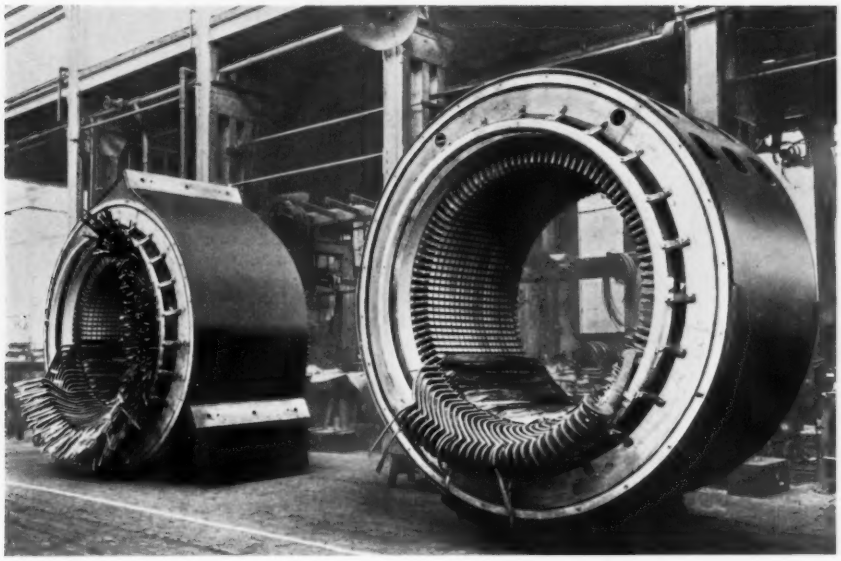

*Fig. 11.*

*Stators of a 7,500 kW. 40/50-cycle Frequency Changer under construction.*

solenoid operated switches and the necessary apparatus for automatic starting after the main oil-breaker has been closed. The motor power factor and the generator voltage will be controlled automatically. A second unit of the same design and output has recently been put in hand.

## CONSUMERS' INSTALLATIONS.

Considerable progress has already been made with the work of changing motors in the Central Scotland area ; less has been done in the Birmingham area, whilst in the Newcastle districts it has barely commenced. Not unnaturally, perhaps, power consumers have had some doubts as to the procedure to be followed, and concerning the incidence of the expenditure involved, but their position will always be made quite clear by the local supply authority acting on behalf of the Central Electricity Board. There are two courses open to the consumer when he is called upon to adapt his installation to the new frequency by a certain date. He may agree with the authority for them to carry out the work of exchanging his equipment for one of corresponding size and characteristics and to give consideration to his views on the selection of particular makes and modifications in technical details. Any alterations which mean any expenditure by the Central Electricity Board over and above that necessitated by the exchange of one piece of apparatus for another have to be the subject of negotiation as to the allocation of cost, and therefore in agreeing to a simple changeover, the consumer, whilst freeing himself of any financial liability, ties himself to a large extent to a repeat of his original installation.

The alternative course is for the consumer to negotiate for the changeover to be carried out by himself on consideration of his receiving a lump sum calculated to cover the cost of a new 50-cycle installation equivalent to the old one, including modification of mechanical parts, and the labour required to effect the conversion. The great advantage of this course is that the consumer then has a free hand to reorganise the power arrangements by reconstructing the drives, installing motors of more suitable rating and revising the layout of his substation. The greater flexibility of this scheme is such as to recommend it in every case where an opening can be seen for improvements, and it affords a unique opportunity for bringing an installation up to date at a very moderate cost.

In the case of new motors installed during the changeover period on the old frequency, similar negotiations have to be conducted with the supply authority whose duty it is to see that plant is installed of a type which will require a minimum expenditure when the frequency is changed, having due regard to the consumer's convenience and any related changes that may be necessary on the mechanical side. The importance of this aspect of the changeover may be judged from the estimate that in one of the changeover areas alone about three thousand motors will be newly connected at the old frequency before the conversion is complete.

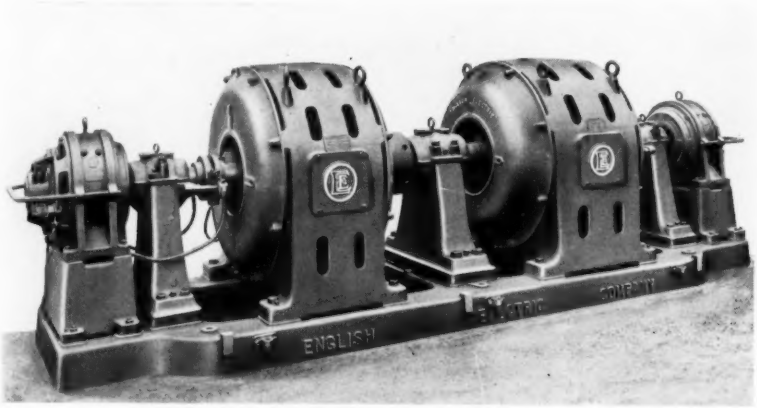

*Fig. 12. 400 kW., 25/50, Transferable Frequency-changer for temporary installation during a works change-over.*

A great deal of thought has been given by the supply undertakings and by manufacturers to finding the most economical methods of dealing with pre-changeover installations. In the later stages of the conversions it becomes possible to draw on the accumulated stock of the old-frequency motors withdrawn from factories where the changeover has been carried out, but even then suitable machines are not always available, and the final balance sheet will contain a not inconsiderable item for the change to the new frequency. A way out of the difficulty was naturally sought in the design of motors capable of being adapted in position from the old to the new frequency, and as will be seen later, a considerable number of so-called dual-frequency machines has been installed in the 25-cycle areas, where the doubling of the frequency corresponds to a reduction in the number of poles on the motor by one-half if the same speed is to be retained. The employment of these machines has the great merit of obviating any great dislocation in the operation of the factory, and they represent a saving in capital expenditure compared with the installation of a straight 25-cycle motor which is afterwards replaced by a straight 50-cycle motor. On the other hand, they are not quite standard machines, and their performance is a compromise between 25-cycle and 50-cycle machines to an extent depending upon the speed and output.

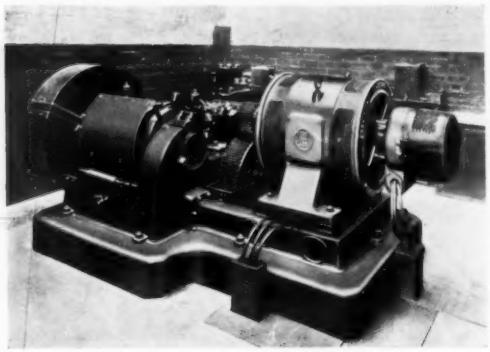

*Fig. 13. 133 H.P. 25/50-cycle motor adapted to existing bedplate of hydraulic pump.*

In the 40-cycle areas the utility of a dual-frequency (reconnect) type of motor is less, because, as already explained, there are very few speeds common to the old and the new frequencies. The design is applicable, however, to large slow-speed motors, especially slipring machines, on colliery winders and similar drives, and by suitable selection the variation of speed in such cases may be made so small that no modification is necessary

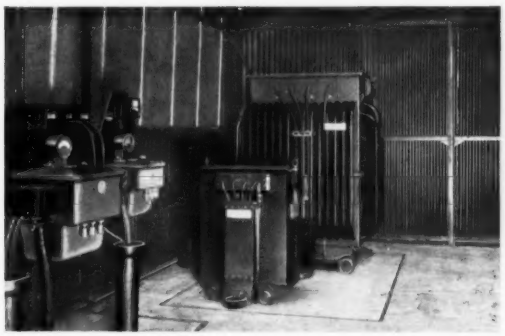

*Fig. 14. 25/50-cycle, 5,000/10,750-volt Industrial Substation.*

to the gearing or other mechanical parts. In these districts a more suitable type of machine for pre-changeover installation is the "inter-frequency" motor, a design which seeks to make the best of the inevitable change of speed due to the 40 to 50-cycle conversion. The change of speed still has to be faced, but the same motor is capable of operating permanently at 50 cycles, although in the interim period it works at 40 cycles. This entails a measure of compromise in the performance characteristics, but provided that a suitable machine is selected it means a considerable saving in outlay and in the disturbance to the factory. Such motors would not, of course, be employed unless their extra cost and the cost of the mechanical alterations to the drives at a later date, together amount to less than the cost of replacement of a straight 40-cycle equipment by a 50-cycle equipment of the nearest obtainable speed. Careful choice of speed is important when contemplating the use of interfrequency machines; if, for example, an 800 r.p.m. motor (6-pole) would have been purchased under the permanent 40-cycle conditions, it will be advisable to consider whether the most suitable inter-frequency machine is one with 6 or 8 poles. The 6-pole motor will run at 1,000 r.p.m. when the frequency becomes 50 cycles, whereas an 8-pole motor will run at 600 r.p.m. on 40 cycles and 750 r.p.m. on 50 cycles. If, in this example, the least possible change of speed is permissible, then the best solution is to install a straight 40-cycle machine which would subsequently be replaced by a straight 50-cycle motor; the reduction in speed amounting to only about 5 per cent., the necessary mechanical adjustments to the drive will be undertaken by the change-of-frequency department.

Many similar considerations arise in the north-east coast changeover, and the advice of experts is indispensable for the power user to obtain the best all-round pre-changeover installation. The "English Electric" inter-frequency type of motor is the best in most cases: it is designed to give the desired output on either frequency, the speed increasing in the ratio of $1 : 1\frac{1}{4}$ when the frequency becomes 50; the design aims, of course, at obtaining the best performance under the permanent, i.e., the eventual 50-cycle conditions. The majority of drives in a factory will have to be modified by changing pulley, pinion or sprocket wheel to compensate for this change of speed. Direct-coupled machines may have to have speed reducing gear added or to be reconstructed or replaced. In certain cases, for example, centri-

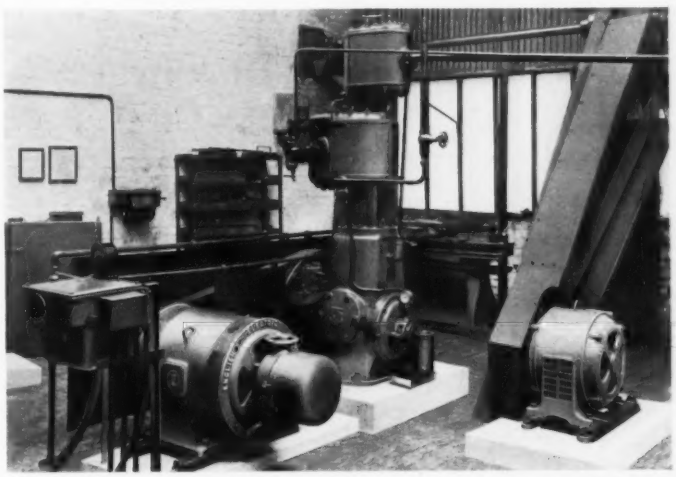

*Fig. 15. 40-H.P. 25/50 Motor driving air compressor and a similar 12½ H.P. machine on line shafting.*

fugal pumps, it is possible to obtain special inter-frequency types which can be modified on site to suit the increased speed.

A recent order from a colliery in this district illustrates the application of several special types of machine to meet the changeover conditions. A double-drum winder is to be driven by a 2,750-volt dual-frequency (reconnect) motor of 640 H.P. (peak), which will be built with 16 poles and arranged for subsequent conversion to 20 poles, the speed remaining 300 r.p.m. A high-lift multi-stage "Drysdale" pump will be driven by a 2,750-volt interfrequency motor giving 310 H.P. at 1,160 r.p.m. on 40 cycles, and the same output at 1,450 r.p.m. on 50 cycles; it is proposed to arrange the pump so that three stages can be discarded and the end covers brought closer together with the provision of a new shaft and tension bolts, and a special pipe bend.

*Fig. 16. Individual Drives by 25/50-cycle motors.*

The great experience of the Company in industrial electrification problems has been widely recognised in the changeover areas, and they have carried out and have in hand a large number of conversion and pre-changeover contracts, some of which are of considerable magnitude, involving complete substation and main switchgear. A valuable opportunity has presented itself to the manufacturer and the power user for the development and adoption of new types of drive of a more economical kind, in a way that would otherwise have been impossible in the existing circumstances of financial stringency; the driving of rolling mills and the extensive adoption of power factor improvement are notable examples of this kind of accelerated progress.

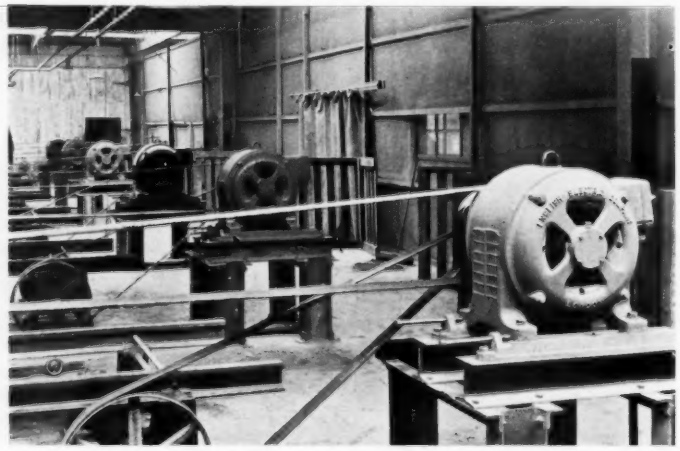

*Fig. 17. 25/50-cycle Motors driving Polishing machines for Stainless Steel.*

Careful attention to a number of details is essential in dealing with the replacement of existing 25-cycle motors. Apart from the mechanical requirement of adapting the new motors to the old foundations, bedplates or other parts, which often calls for careful measurements and modification to standard feet and fixing centres, questions of starting torque and factory power factor well repay investigation. The starting torque of a 50-cycle motor is inherently less than that of a 25-cycle machine of the same normal rating, and to ensure satisfaction

to the consumer it is desirable for torque tests to be made on the existing machines so that the new motors may give the required starting effort; this applies more particularly to motors of the squirrel-cage type. Then, again, the changeover may result in an appreciable reduction of the overall power factor and a consequent increase in the maximum kVA. demand. In areas where it is the practice to charge for power on a kVA. basis or to give some other financial inducement for maintaining a high power factor, the supply authority may have to install as part of the obligation of the Central Electricity Board some form of power factor improvement apparatus. Even if the circumstances do not place this obligation upon them, it may be an advantage for the consumer to undertake the improvement himself and to negotiate with the supply authority for a part or the whole of the additional cost to be borne by them. It is of interest to note that one writer has estimated that on the whole the decrease in power factor when changing over from 25 to 50 cycles may result in an increase of 13 per cent. to 14 per cent. in current, which, in turn, corresponds to an increase of about 30 per cent. in heating effect. This tendency will certainly be an added inducement for the supply undertakings to welcome proposals for power factor improvement.

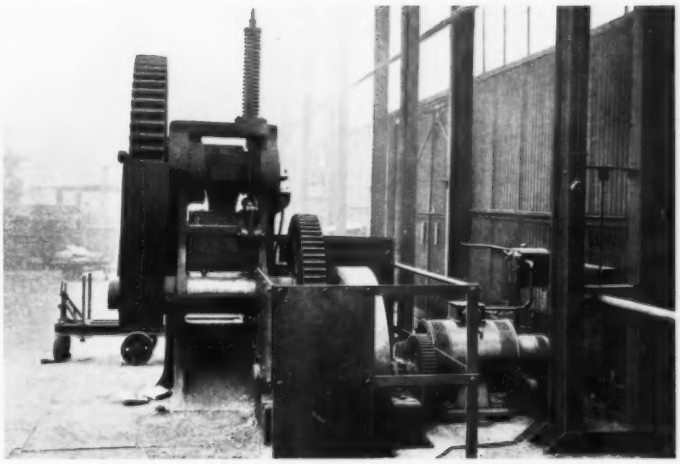

*Fig. 18. 25/50-cycle Motor driving Ingot Shears.*

When dealing with the replacement of motors, it is often necessary to take full measurements and to introduce special modification into the new machines so that they may fit the old drives without any alterations. Fig. 13 shows a 133 h.p. slipring motor with special feet and shaft to suit the existing bedplate and outboard bearing; it is driving a hydraulic pump at the works of Messrs. Mechans, Limited, of Scotstoun, and is operated by contactor gear.

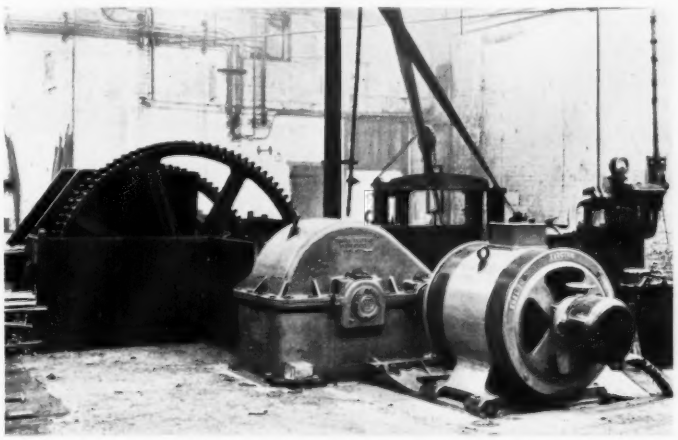

*Fig. 19. 150-H.P., 25/50-cycle Motor on a Wire Mill.*

The changing over of existing installation is now taking place on a large scale in the various districts, but this work has, of course, had to await the preparations of the supply company for giving a supply at the new frequency, in accordance with their time and geographical programme. The magnitude of the changeover operations may be indicated by reference to the

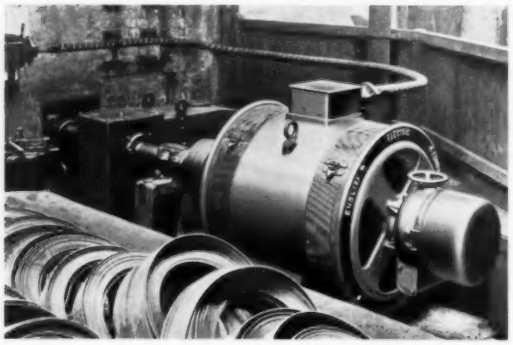

*Fig. 20. 150-H.P., 25/50-cycle Motor in a Rolling Mill.*

contracts in hand for the Motherwell Iron & Steel Company. Instead of merely substituting 50-cycle motors for the existing 25-cycle machines, all of which were of single or two-speed slipring type, the whole of the drives were investigated in the light of the most modern practice, and it was decided to obtain the advantages of unity power factor and variable-speed control on the jobbing mills, together with the elimination of slip losses, by converting the power to direct-current and employing d.c. variable-speed motors. The mills are being rearranged so as to centralise the converting plant as much as possible. The equipment to be supplied comprises the following d.c. motors : For the 16 in. Mill, 500/1,400 h.p. 100/150 r.p.m. direct-coupled to an existing flywheel and complete with contactor starting and control gear with push button control and dynamic braking. For the 10 in. Roughing Mill, 300/700 h.p. 130/260 r.p.m. engine-base type motor direct-coupled to a flywheel on its own bearings and complete with multiple switch type hand starter and interlocked shunt regulator with series divertor. For the 10 in. Finishing Mill and Hard Rolls, 500/1,400 h.p. 150/300 r.p.m. motor direct-coupled without a flywheel to the 10 in. finishing mill and rope driving on to the hard rolls. This equipment is also complete with multiple switch starter. For the 8 in. Mill Drive, 300 h.p. 270/350 r.p.m. motor direct-coupled to an existing flywheel and complete with multiple switch starter and shunt regulator. For Sheet Mill, 750 h.p. motor and control gear.

The 10 in. roughing mill motor and the drive for the 10 in. finishing and the hard rolls are at the substation together with two 750 kW. unity power factor 230/460-volt 3-wire rotary convertor equipments with transformers taking power from the Clyde Valley 11,000-volt 3-phase 50-cycle system.

The fact that these customers decided to go right away from A.C. to D.C. for driving their merchant mills because of the many advantages

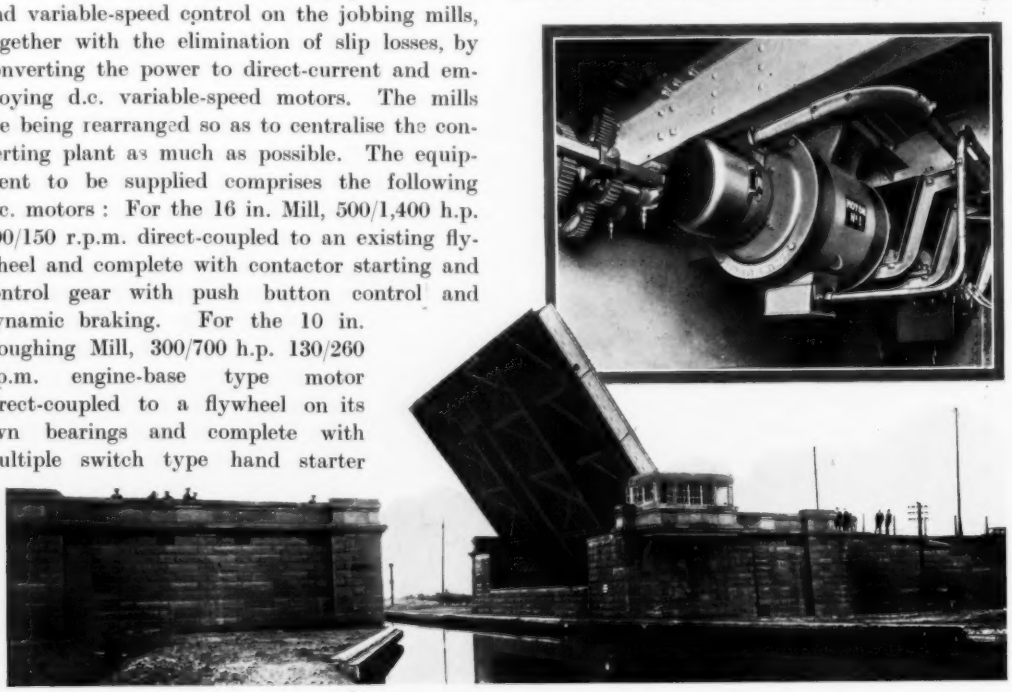

*Fig. 21. Lifting Bridge at Anniesland operated by seven 25/50-cycle Motors. Inset one of the two 20-H.P. motors for raising the 500 ton leaf.*

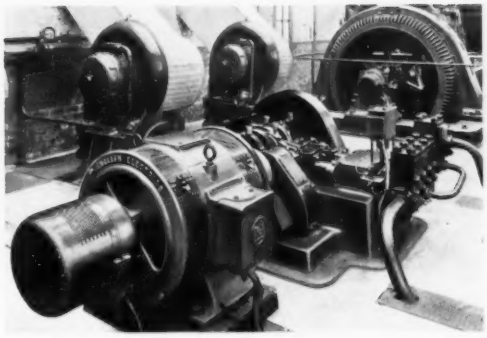

*Fig. 22. 85-H.P., 25/50-cycle Motor driving hydraulic pump, and a 600-H.P. compressor motor rewound for 50-cycles.*

to be obtained is rather noteworthy. By so doing they obtain the full advantages of such a scheme at a minimum of cost to themselves, by negotiating with the Electricity Commissioners for the changeover of their plant, while still leaving themselves a free hand to reorganise their equipment as they thought best.

The order further suggests that on the change of frequency other customers may contemplate the substitution of variable-speed equipments on similar mills for their present single-speed drives, especially if by so doing they can eliminate gearing and obtain increased outputs at very little, if any, further expense.

As an example of the course of events in a representative modern factory in one of the 25-cycle areas, shortly prior to the commencement of the changeover operations, a brief description may be given of the plant installed in a large Rubber Works in the Glasgow Area. An E.H.T. bulk supply was taken at 11,000 volts, and a substation at the works was equipped with two dual-frequency 500-kVA. transformers, a dual-frequency rotary convertor equipment of 150-kW., a high-tension truck-type control board of three panels and low-tension distribution boards for the A.C. and D.C. supplies to the works respectively. A view of the substation is shown in Fig. 5, which also includes a 50-cycle 300 kW. rotary convertor installed after the changeover had occurred. The necessity for a direct-current supply arose from the use of mills and calenders, on which fine speed regulation was required over a wide range. The whole of the equipment was arranged to operate on the 25-cycle supply then available, but it was so designed that, when a year later, the supply frequency was changed to 50 cycles, the transformers and rotary convertors were reconnected and then gave doubled outputs. So far as the A.C. motors in the works are concerned, the changeover was anticipated by the use of 50-cycle machines, and during the transition period, two 25/50 cycle frequency changers, each of 400 kW. were installed at the works by arrangements with the Supply Authority ; one of these machines is illustrated in Fig. 12.

An example of the installation of dual frequency motors in the Birmingham area is that carried out at the works of an old-established firm of galvanizers. The decision to abandon the use of gas engines and to electrify the works was taken when the electric supply available was a 25-cycle, 3-phase, 5,000-volt service, which would ultimately become a 50-cycle, 10,750-volt service. The works' substation, shown in Fig. 14 was equipped with dual frequency transformers of 200 kVA. for the power load, and 25 kVA. for the lighting load, together with the necessary switchgear, which was of 11,000-volt size.

As much of the plant in this works operates intermittently, it was considered desirable to subdivide the drives as much as possible, and use

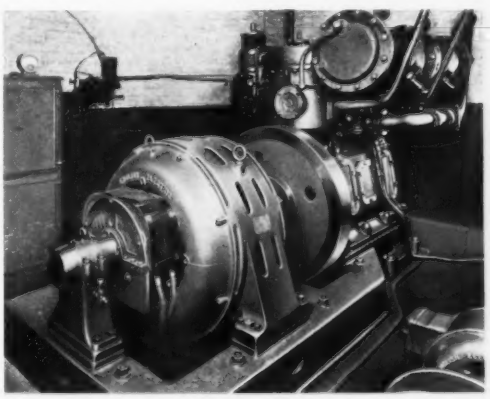

*Fig. 23. 200-H.P., asynchronous-synchronous motor substituted for an induction motor to improve power factor.*

separate motors for as many machines as possible. Fig. 15 shows two dual frequency motors, one a 40-h.p. slipring machine driving an air compressor for pneumatic riveting, and the other a 12½-h.p. squirrel-cage motor driving line shafting. The starters are of the Company's " OSR " stator-rotor type and " OS " star-delta type respectively. Fig. 16 is another example of individual drives in this works by dual frequency motors. The only modification required to the starting apparatus when the frequency is changed will be the replacement of the no-volt coils.

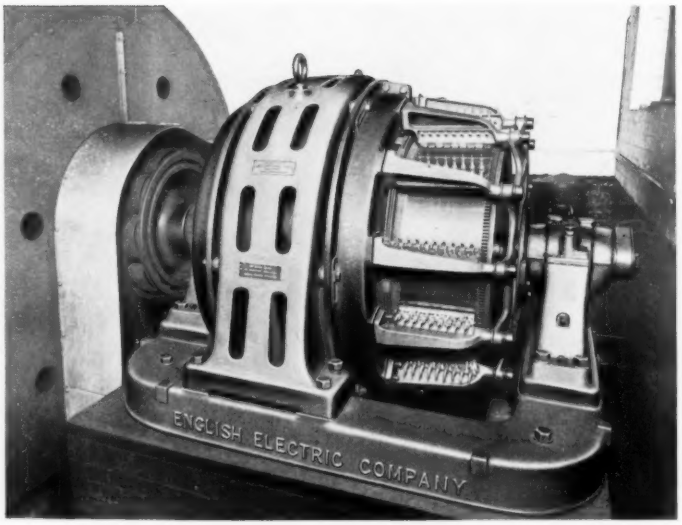


*Fig. 24.—Slip-regenerating Motor on a 2,000 H.P. Sheet Mill Drive.*

Another interesting application of dual frequency machines is shown in Fig. 17, where six squirrel-cage motors are seen driving polishing benches for stainless steel sheets in the works of Messrs. Thomas Firth & Sons. These motors are controlled by the Company's oil-immersed star-delta starters.

An interesting case of the application of dual frequency motors is that illustrated in Fig. 18, which shows what is believed to be one of the first dual frequency slipring machines to be put into service; it is a 20-h.p. machine driving an Ingot shears. The customer to whom this was supplied had one works in a 25-cycle area, and another in a 50-cycle area, and the motor was purchased to operate on 25-cycle mains for about eighteen months, after which it was transferred to the second district where it has since been working at the standard frequency.

Of dual frequency motor installations of somewhat larger size, reference may be made to that of Messrs. Charles Clifford & Sons, who completed last year the electrification of their Dogpool Rolling Mills. Fig. 19 shows a 150-h.p. motor and gear drive on one of the wire mills, and Fig. 20 a second machine of the same size driving another portion of the plant. With the advent of the 50-cycle supply, the complete changeover of this works is now in progress, and new 50-cycle motors have recently been put in hand, comprising machines of 350 h.p., 250 h.p., 85 h.p. and smaller sizes.

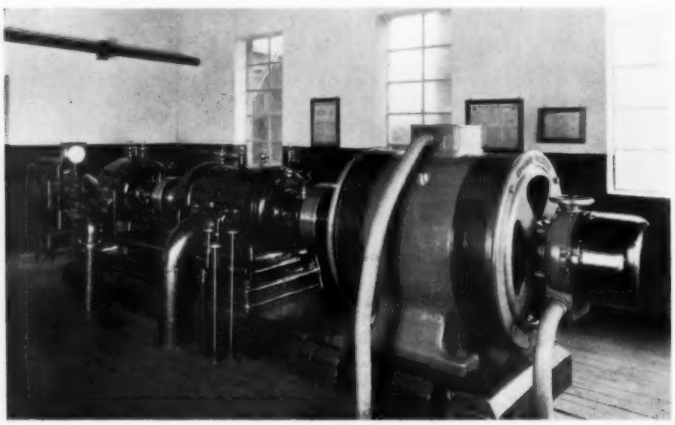

*Fig. 25. 161/200-H.P., 25/50-cycle Induction Motor driving Rotary Compressor.*

A further example of a pre-changeover installation is shown in Fig. 21, reproduced by the courtesy of Sir William Arrol & Co., Ltd. This shows a new lifting bridge at Anniesland, and inset, one of the seven dual-frequency motors that actuate it. This motor is one of a pair of 20-h.p. half-hour rated dual-frequency slipring machines fixed in the 500-ton lifting portion, and driving through horizontal shafts and gear trains. Each motor is capable of performing the full duty although they are used together for normal operation. There are also five smaller motors of the squirrel-cage type installed under the foot-ways of the fixed portions for operating the bolts and gates. The whole of the motors are operated from a master controller by contactors which determine the proper sequence and acceleration automatically.

Fig. 22 shows an 85 h.p. dual-frequency slipring motor operating a high-pressure hydraulic pump at Messrs. John Brown's works. In the background is a compressor driven by a 600 h.p. "English Electric" Motor that has been rewound for 50-cycles to the order of the supply undertaking.

Emphasis has been laid already on the importance of using the changeover for the general improvement of factory driving equipment. There is, too, the question of power factor improvement, and it has been found in many cases that a comparatively small additional outlay at the time of the changeover will enable the consumer to obtain a permanent benefit by qualifying for the rebate, or other inducement, offered by the Supply Authority for the maintenance of a good power factor. Moreover, as the power factor of ordinary induction motors is on the whole lower at 50 cycles than at 25 cycles, some assistance on the financial side may be looked for.

The English Electric Company has always taken special interest in power factor improvement problems, and has developed standard lines of machines of several types for bringing about any desired degree of power factor correction, the choice of type depending upon the circumstances in which the factory operates. A good example of the way in which their asynchronous/synchronous (synchronous induction) motors have been used for this purpose in connection with a frequency changeover, is the installation of three of these machines at the works of Messrs. D. & W. Henderson, in the Glasgow area. The power factor of the installation has been raised to the very satisfactory figure of .98. Fig. 23 shows one of these motors, a 200 h.p. 265 r.p.m. machine, driving an air compressor. Two machines of this size, and a third of 300 h.p. replaced slipring induction motors of the ordinary type, and they were constructed to suit the existing bedplates and other mechanical parts. In the ordinary way, motors of this type are fitted with a direct-coupled exciter, but in the installation in question limitation of space led to the use of separate motor-driven exciters connected up in such a way that when the stator switch of the main motor is closed, the driving motor of its exciter set is thrown directly on to the line, suitable protection being provided by means of thermal overload relays.

An alternative type of power factor correction machine which is very useful in smaller factories, or where the units are of smaller output, is the

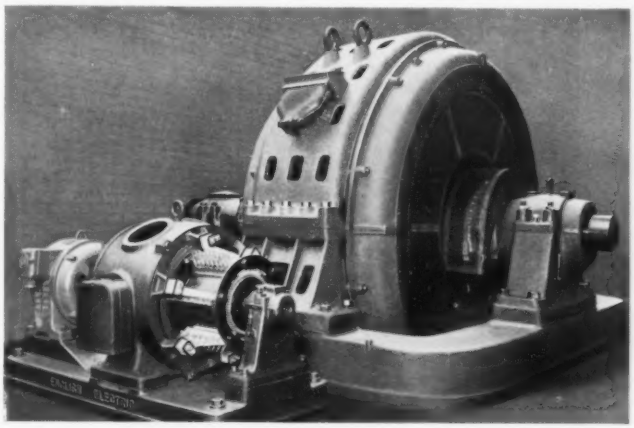

*Fig. 26. 2,500-H.P. Induction Motor with Phase Advancer for power factor correction.*

Company's "Kosfi" compensated induction motor, and extensive use is being made of these, with highly satisfactory results for both the consumer and the supply company.

Both of the above mentioned types of power factor correcting motors are employed to advantage in large works, especially where a considerable proportion of the drives is necessarily by large low-speed motors. For the conversion of a cement works in one of the 25-cycle districts more than ninety motors of various sizes are being supplied. Whilst the majority of these are induction motors, power factor improvement is being carried out by the use of a 350 h.p. asynchronous-synchronous motor to operate at 0.7 leading power factor, and two 22 h.p. "Kosfi-leading" compensated induction motors.

Where it is desired to apply power factor correction to individual induction motors of very large size, the Company employs a rotating power factor compensator in conjunction with an induction motor of the slipring type, and with this combination it is possible to hold the power factor to unity over the whole load range. Fig. 26 illustrates a compensator applied to an induction motor of 2,500 h.p. thereby increasing its power factor from about .7 up to unity, at a very small average cost; the equipment is started and run exactly like a simple induction motor.

The replacement of a 2,500 h.p. induction motor in a rolling mill by a combined slip-regeneration power factor correction equipment illustrates very well how the changeover can be turned to profitable use. An A.C. commutator motor similar to that shown in Fig. 24 is coupled directly to the main motor, and speed control is effected by regulation of the field of the commutator motor. Fig. 25 shows a 25/50-cycle slipring induction motor driving a rotary air compressor in a steel works in the Central Scotland area.

In conclusion attention may be drawn once again to the importance of making full use of the changeover conditions to modernise drives of every kind, and in doing this to institute enquiries as to the latest developments in the economical application of electric power.

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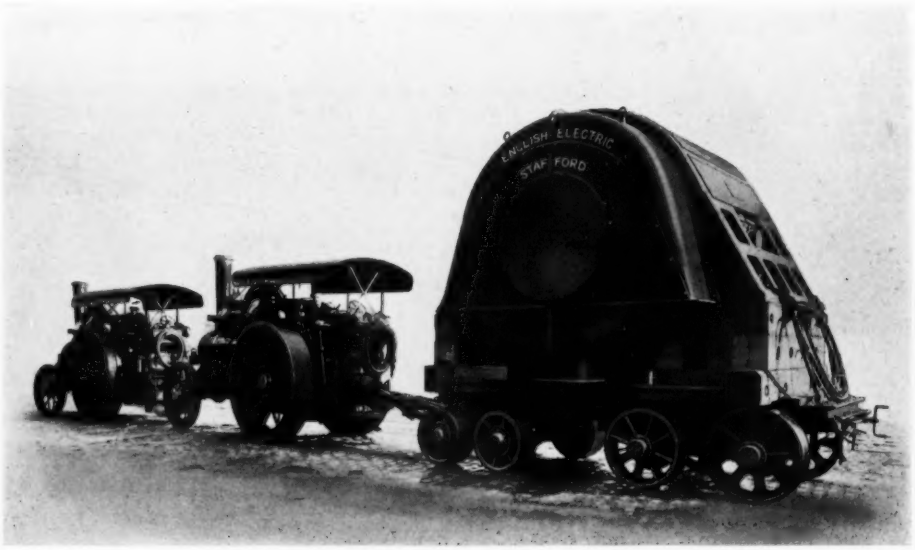


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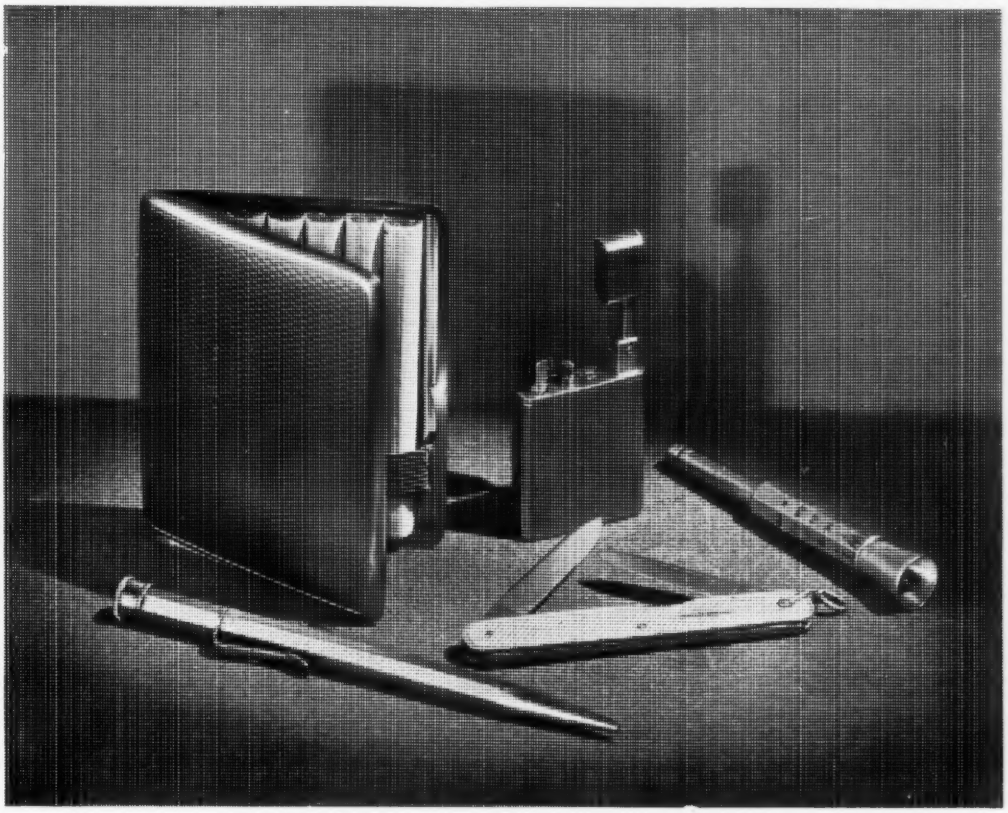

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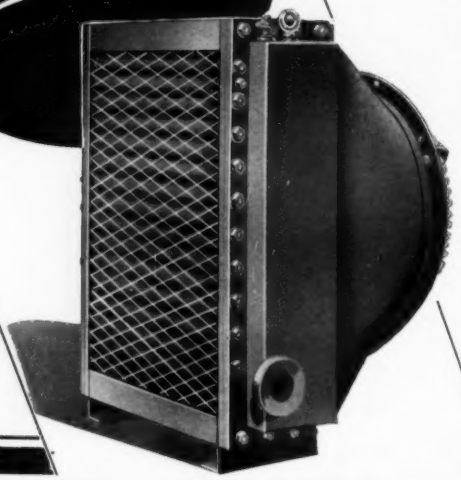

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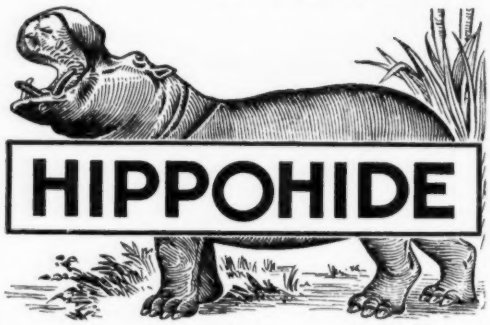


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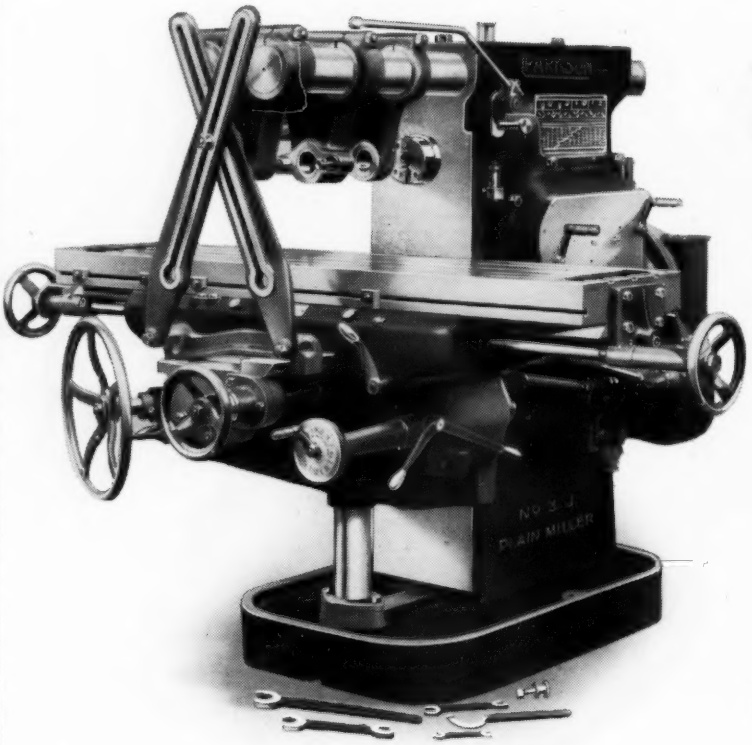

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# INDEX TO ADVERTISERS


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Associated British Machine Tool Makers, Ltd. XVIII
Attwater & Sons .... .... XVI
Box, Norman E., Ltd. .... XII
Broadbent, Thos. & Sons, Ltd. XIII
Craske, Alfred, Ltd .... XV
Davy Brothers Ltd. .... .... V
D. P. Battery Co., Ltd. .... IX
English Electric Company Limited VII, XI
Equipment & Engineering Co. Ltd. .... .... XVII
Heenan & Froude Ltd. .... XVI
London Electric Wire Co. & Smiths Ltd. .... VI
Mason, E. N., & Sons, Ltd..... VIII
Micanite & Insulators Co., Ltd. .... .... .... II
Mitchell Conveyor Co. Ltd. III
Renold, Hans, Ltd. .... XVII
Siemens Brothers & Co., Ltd. X
Spurrier, Glazebrook & Co., Ltd. .... .... .... XIV
Straker Brothers Ltd. .... XX
Strathclyde Paint Co., Ltd. VI
Taylor, Tunnicliff & Co., Ltd. XIV
Tube Products, Ltd. .... XIX
Westinghouse Brake & Saxby Signal Co., Ltd. .... .... IV
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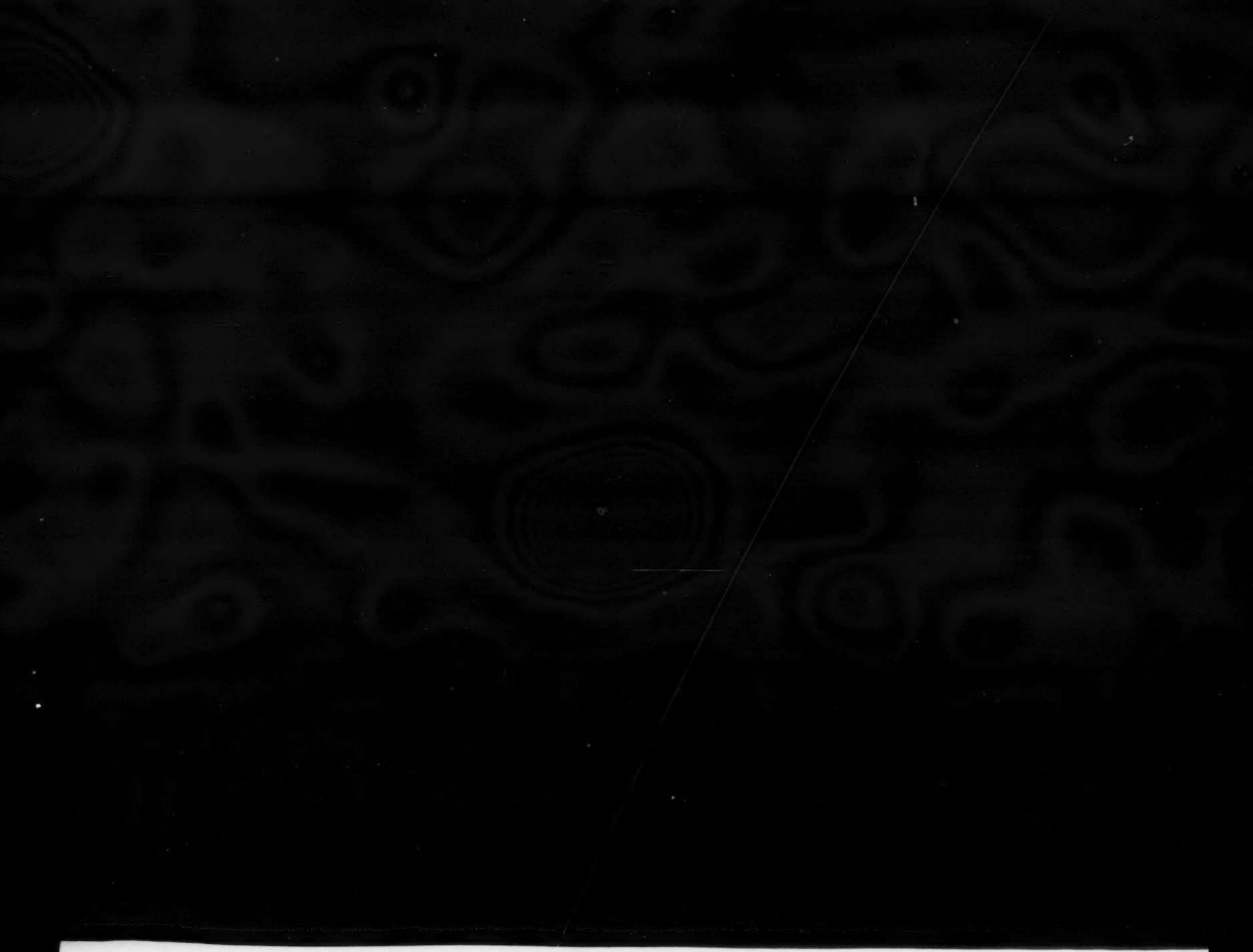
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